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SUMMARY

Stress corrosion data have been obtained from shot peened specimens cut in the short transverse direction from an aluminium alloy extrusion to specification D.T.D. 5054. The specimens were prepared for test in three different ways, to obtain three different residual macro stress systems, typical of the conditions in which the alloy is used in service; it has been shown that, after shot peening, the stress-corrosion properties of each of the three groups of specimens have been improved to a marked extent. X-ray diffraction studies on the specimens have shown that for the particular intensity of peening employed, the resulting highly stressed compressive layer on the surface is of the order 0.006 in. thick and that all evidence of the pre-peening residual stress on the specimen surface has been obliterated. The residual stress measurements show that the balancing tensile stresses are distributed through the remainder of the section rather than concentrated in peak form immediately below the induced surface compression.

CONTENTS

1. INTRODUCTION

It is generally accepted[1,2,3] that shot peening improves the resistance of engineering components to both fatigue and stress-corrosion damage by inducing a thin compressively stressed layer in the surface of the component. However, in the case of stress-corrosion very little quantitative data have been published for the aluminium alloys.

As well as shot peening components as part of the production cycle, it has sometimes become necessary, in the aircraft industry, to shot peen areas of existing aircraft when information has been obtained that these areas could present a stress-corrosion hazard. In more severe cases, cracking on a small scale may already have started and then a typical repair programme could entail the removal of all cracked and corroded metal by local machining, followed by shot peening and finally re-applying a protective coat of some type. It follows that the authorities responsible for deciding to carry out such a repair cycle have to be satisfied that the improvement in resistance to stress-corrosion attack is sufficient to warrant both the withdrawal of the aircraft from service and the provision of the labour and supervision necessary to carry out the shot peening programme satisfactorily.

In order to assess the effect of shot peening on the stress-corrosion properties of the aluminium alloy D.T.D. 5054, specimens were produced which were tested both before and after the peening operation. The manufacture of these specimens was carried out in such a way as to produce specimens typical of the different conditions in which the alloy could be used in service.

2. EXPERIMENTAL

Specimens with a test section of 0.3 x 0.2 in. were machined in the short transverse direction from a 6 x 3 in. D.T.D. 5054 extrusion. This material was supplied in the fully heat-treated and stretched (2%) condition. The major alloying elements were; Zn 6.0, Mg 2.4, Cu 0.74, Cr 0.10, Mn 0.28%.

2.1 Preparation of Specimens

The specimens were prepared for test in three different ways, providing examples with zero, compressive and tensile residual surface stresses prior to the shot peening operation. For ease of future reference these specimens will be referred to as Type A, Type B and Type C respectively.

Type A: These specimens were milled from the extrusion and about half of them were shot peened on all four faces of the central test section with 0.22 in. rust-free chilled steel shot to an Almen Intensity of .008 (standard Almen gauge No.2). The residual surface stress was measured using an X-ray

technique[4]; prior to peening, the stress was within the range $\pm$ 0.3 tons/in^2 and increased to approximately -12 tons/in^2 after the shot peening treatment.

Type B: The as-machined specimens were fully heat-treated, i.e. 1½h at 465°C (in air), quenched into cold water followed by 16h at 135°C. After heat treatment half the specimens were shot peened as detailed above. Residual surface stresses were shown to be in the range -5.0 to -7.5 tons/in^2 before peening and -14 tons/in^2 after peening.

Type C: The as-machined specimens were cold formed to a circular arc using 8 in. radius male and female formers; they were then fully heat-treated as for Type B, thus removing the residual stresses due to forming. The specimens were then straightened using a series of larger radius formers, resulting in surface stresses that would be positive on one side only; this stress was shown to be in the range +6.0 to +9.5 tons/in^2. Only those specimens that were straight and exhibited no severe stress gradient along the surface were subsequently tested. Finally, half these specimens were shot peened, as above, and the residual surface stress was then shown to be of the order -13 tons/in^2.

2.2 The Stress-Corrosion Test

The stress-corrosion test was carried out on a multi-station, single-cantilever type testing machine, in which the specimen was clamped at one end in a horizontal position. A salt solution consisting of 0.5 N sodium chloride and 0.005 N sodium bicarbonate made up in de-ionised water, dripped on to the test section of the specimen. Immediately prior to the stress-corrosion test the specimens which had not been shot peened were lightly polished in their longitudinal direction with 600 grade emery paper, whereas the shot peened specimens were degreased only. The applied stress and time to failure were recorded for each specimen. The residual stress patterns through the thickness of specimens Type A and Type B were symmetrical, but in the case of Type C, care was taken to ensure that the surface of the specimen which had been in residual tension after straightening was mounted uppermost on the stress-corrosion rig.

2.3 Physical Properties

The short transverse tensile properties of D.T.D. 5054 are shown in Table 1 for specimens Types A, B and C in the pre-shot peened condition. All specimens were checked for hardness on a Vickers pyramid hardness testing machine; a hardness between 180 and 195 was considered acceptable.

2.4 X-ray Investigations

It would be expected that any improvement in the stress-corrosion properties after shot peening would be due to the induced compressive layer in the surface. It would be informative, then, to determine the depth of the worked layer and also the variation with depth of the stresses resulting from the peening operation. X-ray diffraction techniques were used to give information on both these points.

To determine the depth of the worked layer due to peening, back reflection X-ray diffraction photographs of specimens of each type were taken using copper radiation, and the resolution of the $K\alpha_1$ $K\alpha_2$ doublet was observed. The surfaces of the specimens were removed in 0.001 in. steps by light metallographic polishing concluding with a mixed acid (HCl, HNO_3 and HF) etch at each step. Back reflection photographs were repeated at these intervals and the process continued until the initially broad $\alpha_1 \alpha_2$ doublet was clearly resolved into its two components, indicating that the metal contributing to the diffraction pattern was not significantly deformed plastically.

To determine the residual stress in relation to the depth of the layer examined below the original surface, it is necessary either to make a correction to the measurement at each depth examined for the stressed material removed or to restrict the specimen in such a way that relaxation during surface layer removal cannot take place. It was decided to adopt the latter technique and the specimens examined were rigidly screwed to a 4 x 1 x 1 in. flat ground steel base. The removal of the surface layers was carried out in appropriate steps by mechanical filing with a clean sharp file, metallographic polishing through a range of papers from 220 to 400 grade and finally a mixed acids etch for 1½ mins. A multi-exposure X-ray back reflection technique[4] was used to measure the residual stress at each exposed level. As shown previously for aluminium alloys, filing followed by mechanical polishing and etching treatments do not significantly alter the macro surface stress[4].

This technique, destructive for the specimens examined, was carried out on one specimen of each type, before and after shot peening. In the case of Type C, the examination was restricted to that surface which was in residual tension prior to peening.

3. RESULTS

The results of the stress-corrosion tests, before and after shot peening, on Types A, B and C specimens are shown in Figs. 1, 2 and 3 respectively. The lower curve in each figure corresponds to specimens before shot peening and the upper curve to the shot peened specimens. Points with an arrow indicate unbroken specimens.

The depth of the worked layer, as determined by the resolution of the α_1 α_2 doublet, was shown to be about 0.006 in. for each type of shot peened specimen. It should be noted that when using this X-ray technique, allowance must be made for the effective penetration of the X-ray beam. Thus, when 0.005 in. of the surface material had been removed, the resulting information obtained from the diffraction pattern has been reported as that from a depth of 0.006 in. below the original surface; in actual fact this information is an average result, typical of the first 0.0015 to 0.002 in. of the examined surface.

The change in residual stress with depth below the surface of the specimens, before and after shot peening for Types A, B and C is shown in Figs. 4, 5 and 6 respectively. In the case of Type C, the stresses shown in Fig.6 have had a correction applied to them, since, after the shot peening operation, these specimens were slightly deformed to the arc of a circle (about 100 in. radius), and on clamping to the flat steel base, a bending stress had been imparted to them. This distortion after shot peening was due to the fact that the outer fibre stresses prior to the peening operation were positive on one side of the specimen and negative on the other side, so that after shot peening a large change in residual stress occurred on one side of the specimen and only a nominal change on the side that was already in compression. No distortion occurred in Types A and B because the residual stress distribution was symmetrical before and after peening.

The degree of uncertainty in the values of the X-ray stress ranges from about $\pm$ 1.5 tons/in^2 at stress levels in the region of 14 tons/in^2 to $\pm$ 0.5 tons/in^2 at stress levels below about 5 tons/in^2.

4. DISCUSSION

The shot peening technique used in this investigation induced a high residual compressive stress and heavy cold work through the first .006 in. of the surface layers of the specimens, resulting in a very marked improvement in the stress-corrosion properties of each of the three groups of specimens. A recent paper[5] has shown that microstresses resulting from cold work have no apparent effect on the stress-corrosion properties, and

the improvement shown here must therefore be due to the induced compressive macro-stress. It is interesting to note that prior to shot peening, the compressive surface stresses in Type B specimens, due to the heat treatment, were not of sufficient magnitude to prolong the lives of the specimens, though they had a significant effect on the time required for crack initiation[6].

To obtain the full benefit from shot peening, the normally accepted precautions should of course be observed; these are, uniformity of peening and protection of the new surface from mechanical damage.

A controversial point in the past has been whether the balancing tensile stresses, resulting from such a shot peening operation, are distributed through the remainder of the section or are concentrated in peak form immediately below the compressive surface layers. Figs. 4, 5 and 6 clearly show that these balancing stresses are distributed through the rest of the section, a situation which is to be preferred for stress-corrosion resistance.

In conclusion it is interesting to note that the shot peening operation has resulted in similar residual surface stresses on each of the three different types examined, irrespective of the initial value of the surface stress. Also, the better resistance to stress-corrosion shown by Type A specimens can be attributed to the slower quench rate, as has been discussed previously[6].

During the course of this investigation it was noted that the stress-corrosion properties of the specimens before shot peening were apparently better than those previously reported[6] for specimens from the same extrusion when distilled water had been used in the salt solution. In case there had been any structural change along the extrusion, this effect was investigated and some specimens were broken using distilled water in the solution; it was confirmed that the use of de-ionised water gave slightly better stress-corrosion properties than the use of distilled water.

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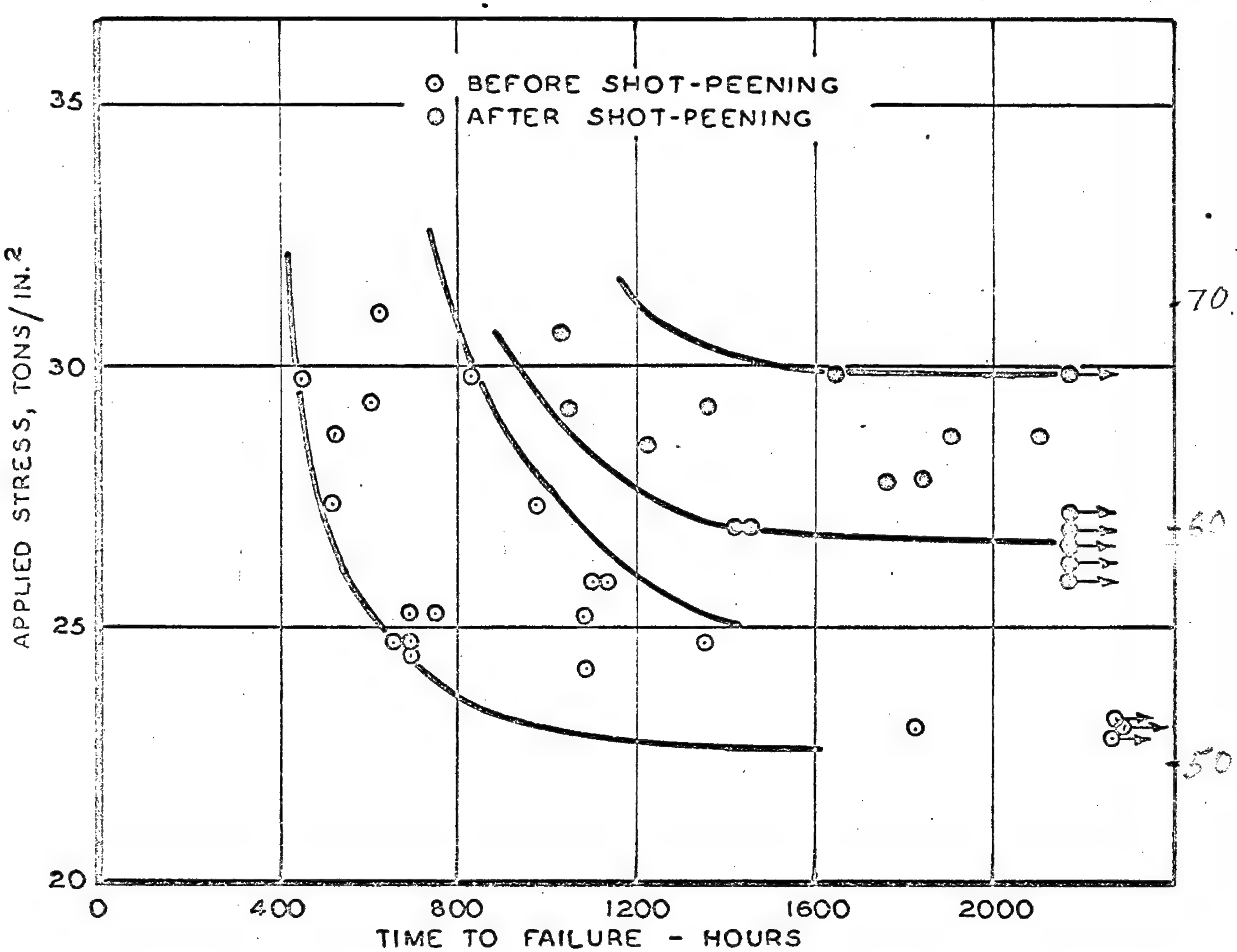
TABLE 1

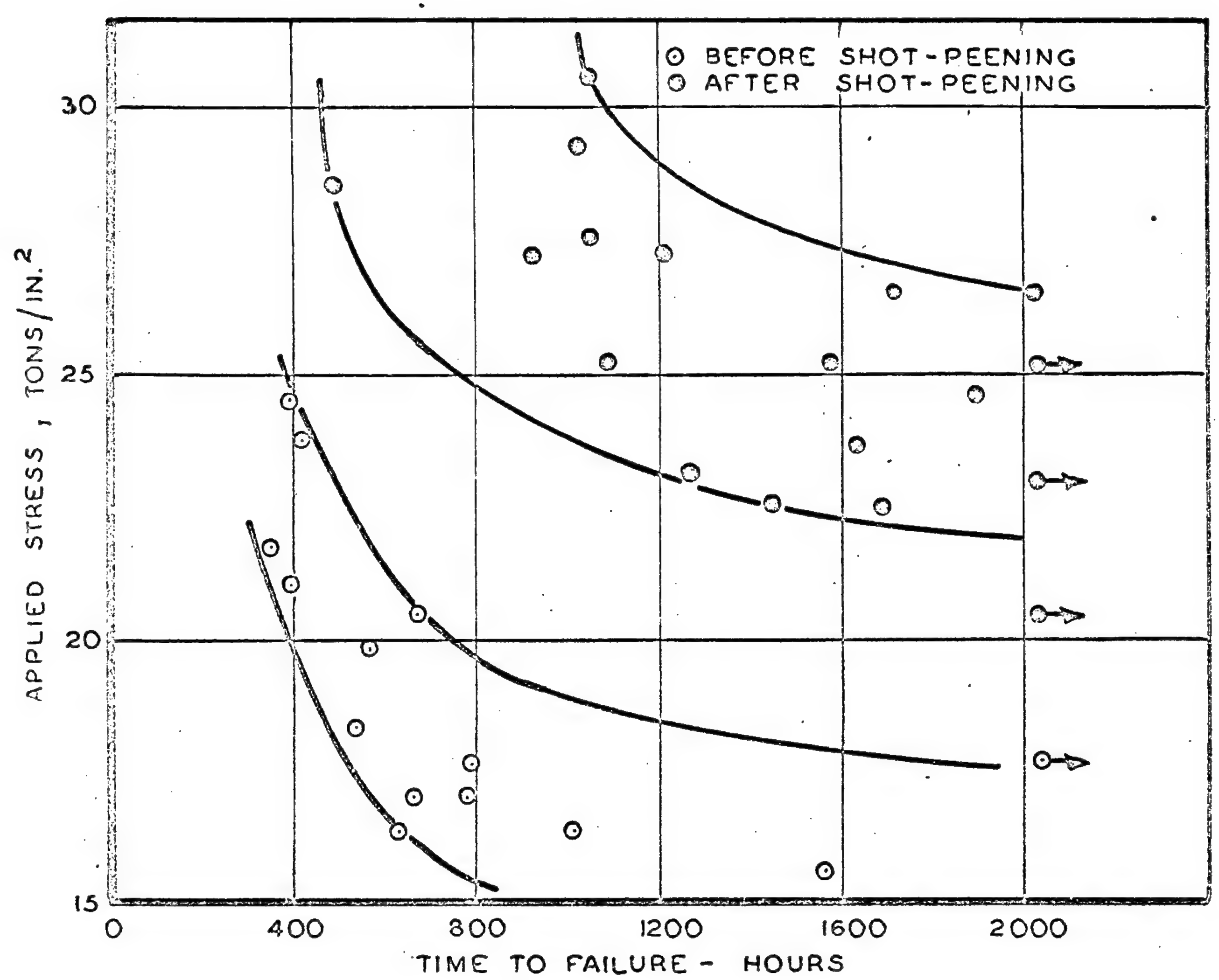
SHORT TRANSVERSE TENSILE PROPERTIES OF D.T.D.5054

State of Material	TS, tons/in^2	0.1% PS, tons/in^2	Elong., %
As machined from extrusion (Type A)	33.2	28.6	3.3
Fully heat treated after machining (Type B)	33.5	29.0	3.8
Bent, fully heat-treated and straightened (Type C)	32.0	26.0	5.0

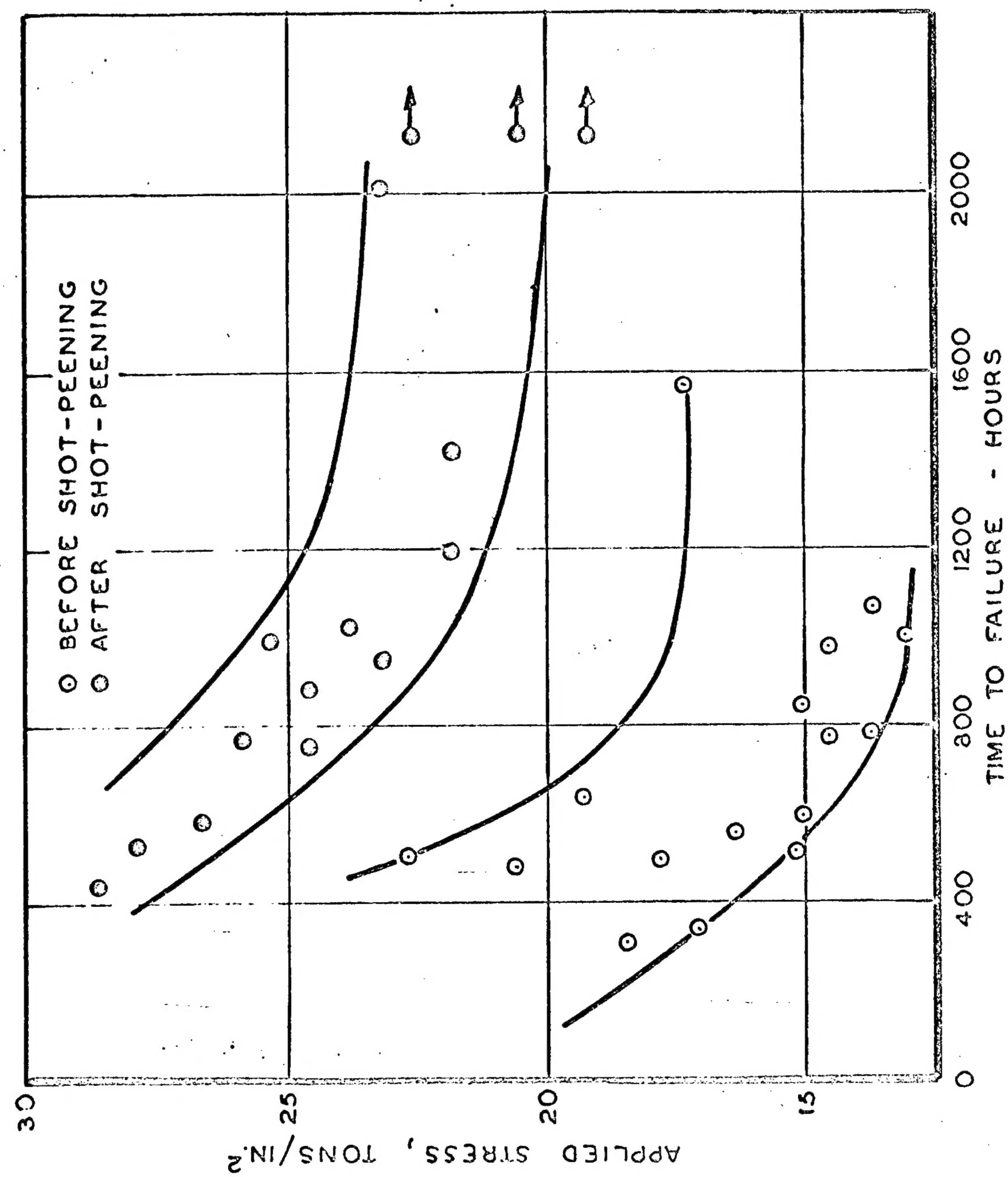
MET. NOTE 52
FIG. 1



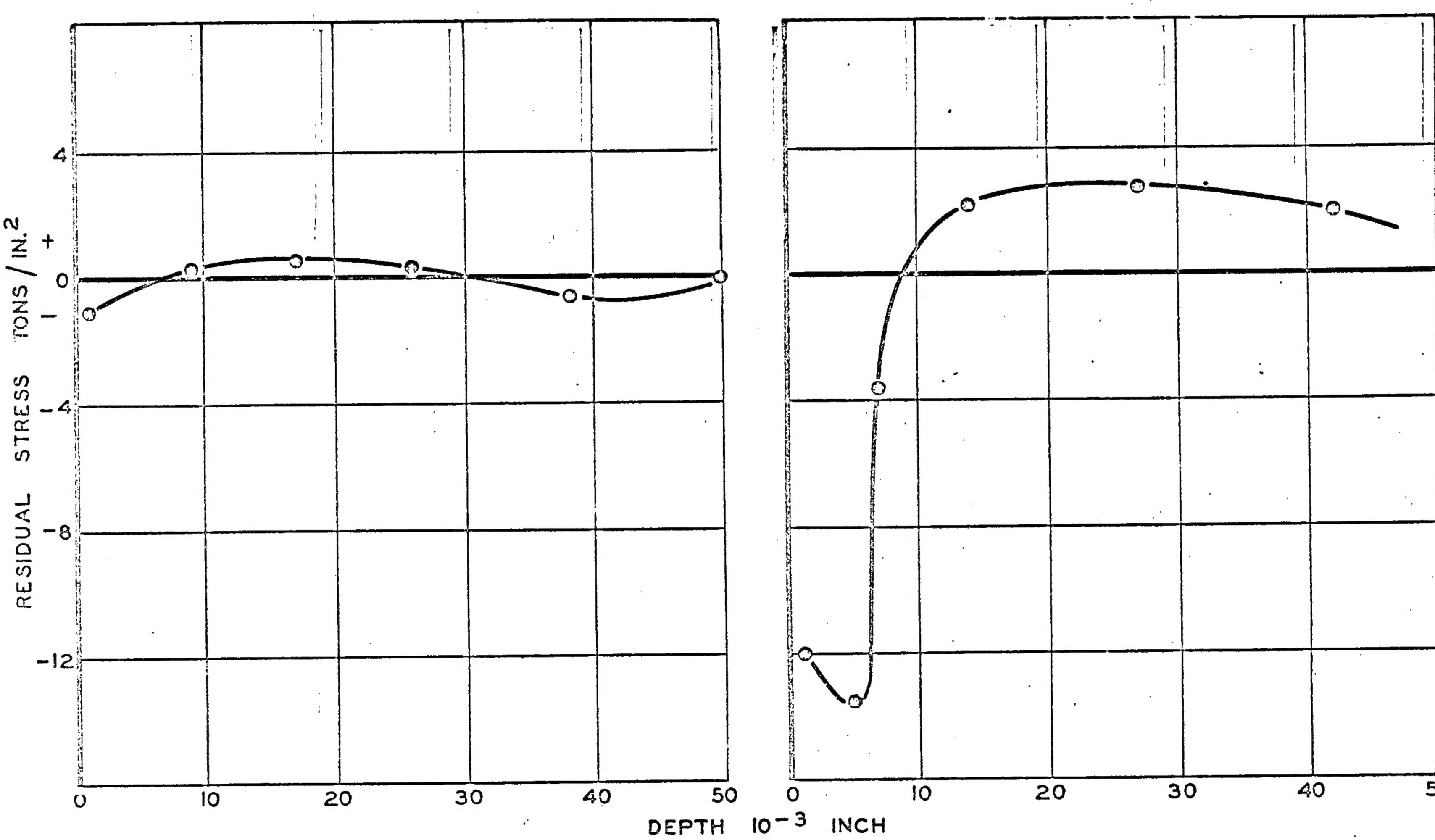
STRESS-CORROSION DATA FOR D.T.D. 5054, TYPE 'A' SPECIMENS
(AS CUT FROM THE EXTRUSION)



STRESS-CORROSION DATA FOR D.T.D. 5054, TYPE 'B' SPECIMENS
(HEAT TREATED IN SPECIMEN FORM)



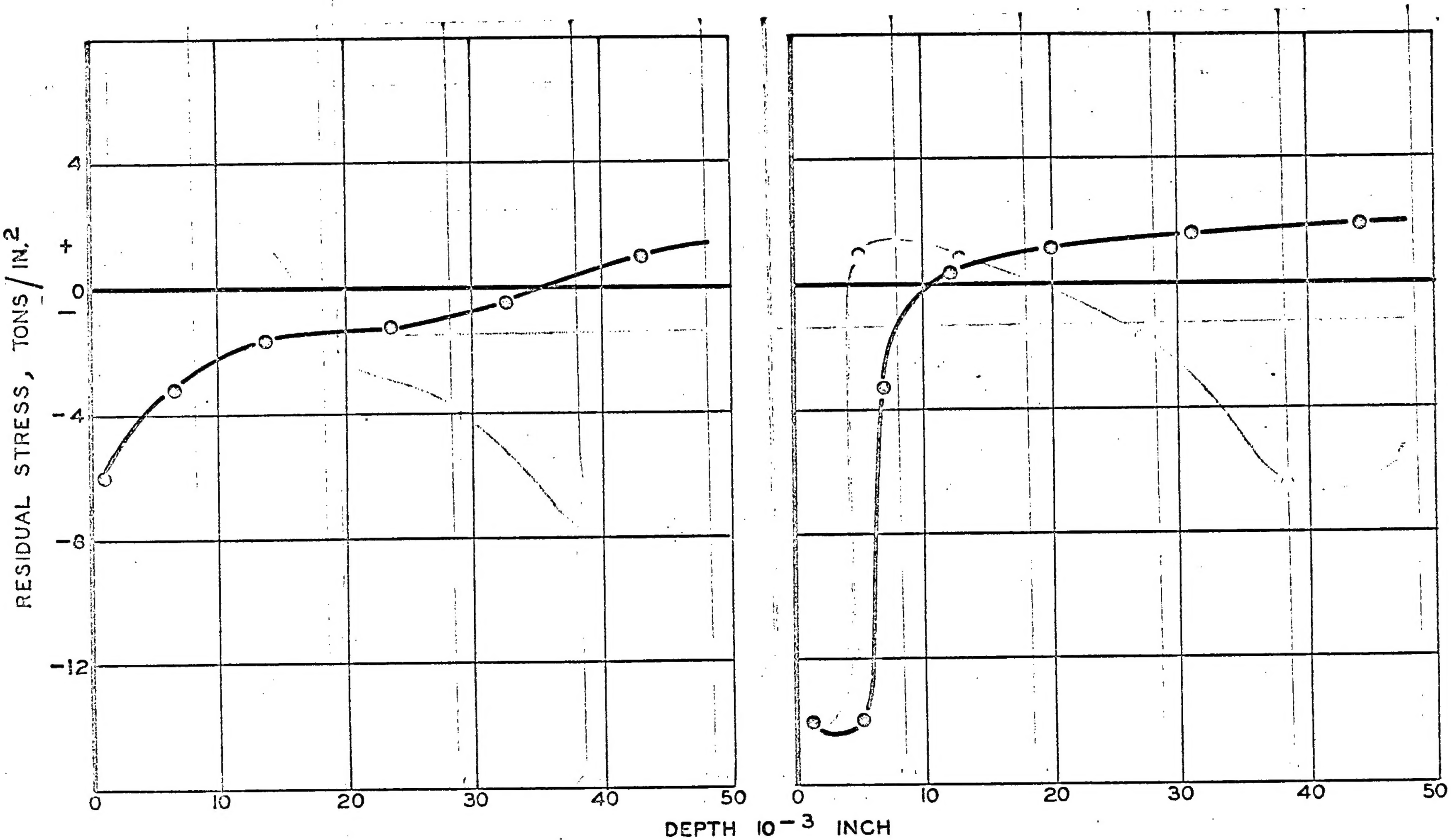
STRESS-CORROSION DATA FOR D.T.D. 5054, TYPE C SPECIMENS
(BENT, HEAT TREATED, STRAIGHTENED)



4 (a)
BEFORE SHOT PEENING

4 (b)
AFTER SHOT PEENING

VARIATION OF RESIDUAL STRESS WITH DEPTH IN SPECIMENS TYPE A, (AS CUT FROM EXTRUSION) SPECIMEN THICKNESS 200×10^{-3} IN.



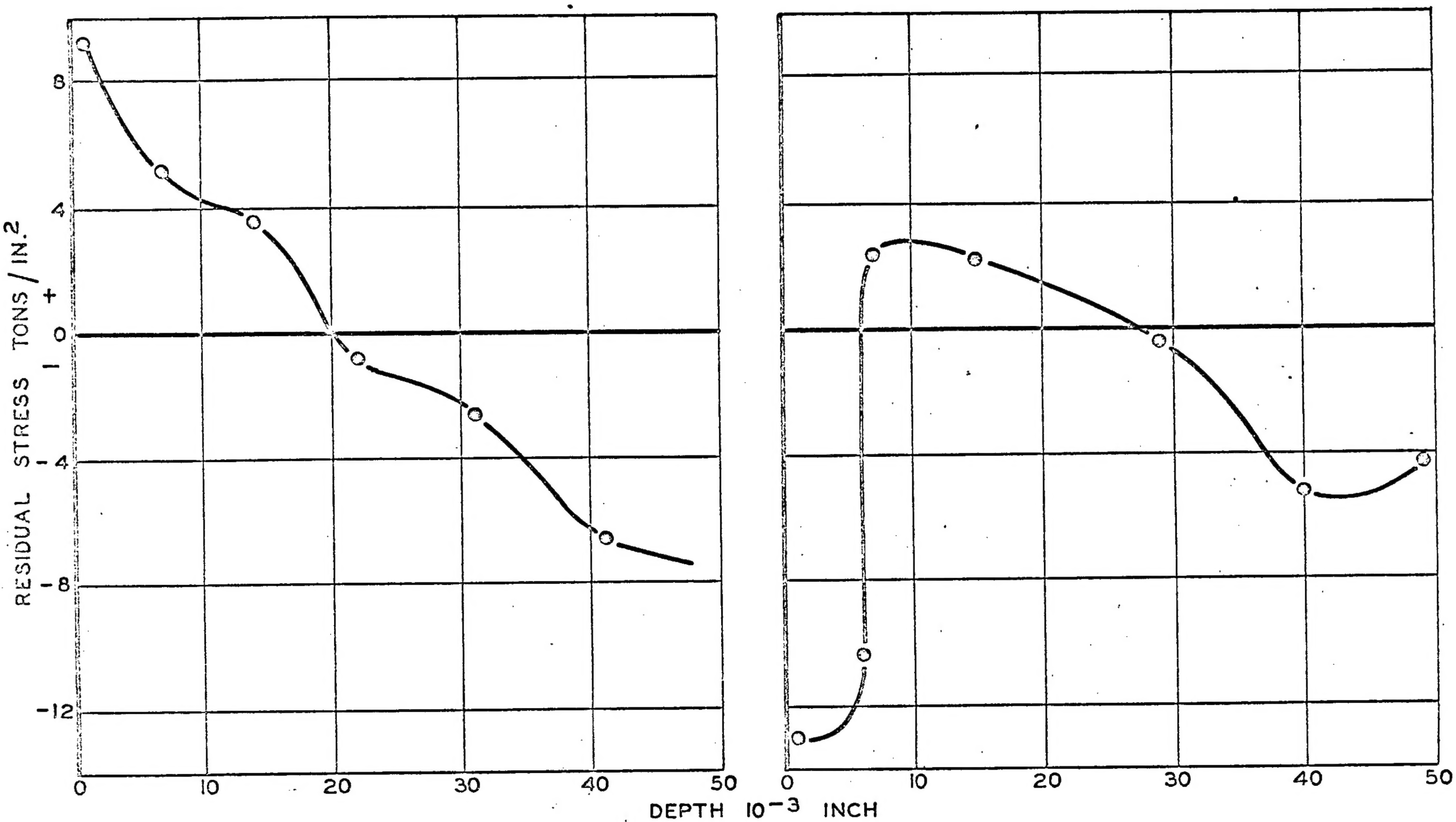
5 (a)

BEFORE SHOT PEENING

5 (b)

AFTER SHOT PEENING

VARIATION IN RESIDUAL STRESS WITH DEPTH IN SPECIMENS TYPE B (HEAT TREATED IN SPECIMEN FORM) SPECIMEN THICKNESS, 200×10^{-3} INCH



6 (a)

BEFORE SHOT PEENING

6 (b)

AFTER SHOT PEENING

VARIATION OF RESIDUAL STRESS WITH DEPTH IN SPECIMENS TYPE C, (BENT, HEAT-TREATED, STRAIGHTENED) SPECIMEN THICKNESS 200×10^{-3} INCH